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BROADBAND ANTENNAS

DOCUMENTS INCORPORATED BY REFERENCE

[0001] The following documents are hereby incorporated by reference into this specification: Rogers, Dennis L., "Monolithic Integration of a 3-GHz Detector/Preamplifier Using a Refractory-Gate, Ion-Implanted MESFET Process", IEEE Electron Device Letters, 1996, EDL-7, pp. 600-602; Albares, D. J., Garcia, G. A., Chang, C. T., and Reedy, R. E., "Optoelectronic Time Division Multiplexing", Electronic Letters, 1987, 23, pp. 327-328; and Mendel'son, V. L., Kozlov, A. I., and Finkel'shteyn, M. I., "Some Electrodynamic Models of Ice Sheets, Useful in Radar-Sounding Problems", Izvestiya Akademii Nauk SSR, Fizika Atmosfery I Okanea, 1972, 8, pp. 396-402 [translated in Izvestiya Academy of Sciences USSR, Atmospheric and Oceanic Physics, 1972, pp 225-229].

BACKGROUND OF THE INVENTION

16
17 **[0002]** Numerous scientific, civilian, and military
18 applications require both narrowband and broadband
19 communications. In typical applications, space and/or weight
20 are at a premium and multiple frequency operation is necessary.
21 Under these circumstances, using multiple antennas or larger
22 broadband antennas is not practical. The use of a single
23 antenna would eliminate cross-talk problems typically affecting
24 multi-antenna systems, especially critical in shipboard and
25 aircraft systems.

26 **[0003]** When limited space is a factor and multiple frequency
27 operation is necessary, reconfigurable antennas provide
28 flexibility in operating frequency, bandwidth, and radiation
29 pattern performance. To be reconfigurable, prior designs have
30 implemented optoelectronic or microelectromechanical systems
31 (MEMS) switches placed along the antenna for control and
32 sampling of electrical signals. These devices are ideal for
33 reconfiguring antennas to different lengths, allowing for
34 multifunctioning of the antennas. In particular, there is a
35 need to have broadband antennas that can be reconfigured into
36 narrowband antennas with high gain or high directionality and
37 back to broadband for some applications.

38 **[0004]** A prior art concept is depicted schematically in

FIG. 1, where optoelectronic switches 12a, 12b, 14a, and 14b interconnect dipole antenna 20 with antenna segments 22a, 22b, 24a, and 24b. The activating light is provided via optical fibers 30, resulting in complete isolation of the optoelectronic switches 12a, 12b, 14a, and 14b. When the light sources 40 and 42 are in a non-emissive state, antenna segments 22a, 22b, 24a, and 24b are inactive and dipole antenna 20 has a length L with output frequency F_1 at time t_1 . When light source 40 is placed in an emissive state, optoelectronic switches 12a and 12b are actuated, thereby activating antenna segments 22a and 22b to form a dipole antenna with length $2L$ and output frequency F_2 at time t_2 . When light source 42 is placed in an emissive state, while light source 40 is also in an emissive state, optoelectronic switches 14a and 14b are actuated, thereby activating antenna segments 24a and 24b to form a dipole antenna with length $3L$ and output frequency F_3 at time t_3 . The disadvantage of this system, however, is that the antenna effectively samples only one frequency at a time. During the time that this one frequency is being observed, all of the information transmitted or received at other frequencies is lost. Thus, there is a need for a variable length antenna that may be switched to allow fast sampling over an entire frequency range, providing the equivalent frequency coverage of a

62 broadband antenna while maintaining the high efficiency of a
63 narrowband antenna.

SUMMARY OF THE INVENTION

1
2 **[0005]** The present invention is a variable length antenna
3 that may be switched to provide the equivalent function of a
4 broadband antenna. It is an apparatus and method for quasi-
5 continuously transmitting or receiving signals at a plurality of
6 frequencies by changing the effective length of the antenna
7 using a variety of switching mechanisms. The antenna of the
8 present invention may comprise a plurality of antenna segments,
9 a plurality of selectively actuatable switches for interconnecting
10 the antenna segments, and a switching mechanism operably coupled
11 to the plurality of selectively actuatable switches for switching
12 them at a switching rate that is greater than twice the highest
13 frequency to be transmitted or received. This rate will be fast
14 enough to allow the antenna to sample the highest frequency and
15 all of the required lower frequencies within the desired
16 frequency range without the loss of information at any
17 frequency. The switching rate is slow enough, however, to allow
18 sampling of the frequency at each antenna length before the next
19 antenna length is activated.

20 **[0006]** An example of a variable length antenna in accordance
21 with the present invention comprises a plurality of antenna

22 segments, a plurality of selectively actuatable switches for
23 interconnecting the antenna segments, a switch controller, and
24 at least one light source. The light source(s), such as lasers,
25 pulsed lasers, light-emitting diodes (LEDs) and diode lasers,
26 may be operably coupled to the actuatable switches by a variety of
27 means, including optical fibers, optical waveguides, optical
28 switches, light valves, or optical MEMS devices. The switch
29 controller selects and switches the light source(s) from a non-
30 emissive state to an emissive state or from an emissive to a
31 non-emissive state. As the switch controller places each light
32 source in an emissive state, the actuatable switches are
33 selectively actuated, thereby activating selected antenna
34 segments and changing the length and effective frequency of the
35 antenna. When the variable length antenna has cycled through
36 the desired transmit or receive frequency range, the light
37 source(s) is/are returned to a non-emissive state and the
38 sampling process repeats.

39 **[0007]** Another example of a variable length antenna in
40 accordance with the present invention comprises a plurality of
41 antenna segments, a plurality of selectively actuatable switches
42 for interconnecting the antenna segments, a switching device
43 operably coupled to at least one light source for actuating the
44 plurality of actuatable switches, and a delay mechanism operably
45 coupled to said at least one light source for effecting delay in

46 actuating the plurality of selectively actuatable switches. The
47 delay mechanism may comprise optical retarders operably coupled
48 to optical fibers to change the effective lengths of the optical
49 fibers. Alternatively, the physical lengths of optical fibers
50 may be varied to achieve the same delay effects of optical
51 fibers. The switching device simultaneously switches the light
52 source(s) from a non-emissive state to an emissive state or from
53 an emissive to a non-emissive state. When the variable length
54 antenna is activated, the switch device simultaneously places
55 each light source in an emissive state. The optical retarders
56 introduce different amounts of time delay into the optical
57 fibers, the actuatable switches are sequentially activated and
58 thereby activating selected antenna segments and increasing the
59 length and effective wavelength of the antenna. When the
60 variable length antenna has cycled through the desired transmit
61 or receive frequency range, the light sources are returned to a
62 non-emissive state and the sampling process repeats.

63 [0008] Yet another example of a variable length antenna in
64 accordance with the present invention comprises a plurality of
65 antenna segments, a plurality of selectively actuatable switches
66 for interconnecting the antenna segments, a light source
67 operably coupled to a switching device, at least one diffraction
68 grating operably coupled to the light source, and a delay
69 mechanism operably coupled to said at least one diffraction

70 grating for effecting delay in actuating said plurality of
71 selectively actuatable switches. The switching device switches
72 the light source from a non-emissive to an emissive state or
73 from an emissive to a non-emissive state. When the light source
74 is placed in an emissive state, the light passes through the
75 diffraction grating(s) to produce a plurality of new light
76 sources after diffraction. Each new light source then
77 selectively actuates the actuatable switches to activate
78 corresponding antenna segments and change the effective length
79 of the antenna.

80 [0009] In accordance with the present invention, transmitting
81 or receiving signals at a plurality of frequencies may be
82 accomplished by employing conductive fluid to change the
83 effective length of the antenna. The antenna may comprise a
84 plurality of antenna segments, each of which comprises a
85 dielectric container for holding a conductive fluid. In this
86 embodiment, the antenna may further comprise a reservoir
87 connected to the antenna segments and a pressure regulator
88 system for controlling the pressure in the antenna segments. As
89 the pressure in the antenna segments changes, the effective
90 length of the antenna changes. This allows the antenna to be
91 tuned to both harmonically related and non-harmonically related
92 frequencies.

93 [0010] In accordance with other aspects of the present
94 invention, transmitting or receiving signals at a plurality of
95 frequencies may be accomplished by using an electromagnetic beam
96 to change the effective length of the antenna. The antenna may
97 comprise a plurality of antenna segments and a source of at
98 least one electromagnetic beam for effectively decoupling the
99 antenna segments. Illuminating a section of the antenna segment
100 with an electromagnetic beam decouples the segment of the
101 antenna beyond the point of illumination from the rest of the
102 antenna and, thus, changes the effective length of the antenna.
103 When the section is no longer illuminated with an
104 electromagnetic beam, it recouples to the rest of the antenna.

105 [0011] An important advantage of this invention is that it
106 provides a broadband antenna using a single variable length
107 antenna, thus simplifying the construction of antenna arrays.
108 This feature is important because RF communications systems may
109 employ one antenna embodying various features of the present
110 invention instead of multiple antennas, which would otherwise be
111 necessary to cover the same bandwidth. This antenna is expected
112 to find wide applications in communications applications,
113 particularly on board ships and airplanes.

114 [0012] Moreover, the broadband sampling technique of the
115 present invention has applications beyond conventional
116 communications systems. For example, the multi-frequency

117 aspects of the invention will allow applications of
118 electromagnetic sounding for surveillance and non-destructive
119 testing. One such application in radar sounding is described in
120 Mendel'son et al mentioned above.

121 [0013] These and other advantages of the invention will
122 become more readily apparent upon review of the following
123 description, taken in conjunction with the accompanying figures
124 and claims.

1 BRIEF DESCRIPTION OF THE DRAWING

2 [0014] FIG. 1 is a schematic of a prior art reconfigurable
3 antenna.

4 [0015] FIG. 2 is a schematic drawing of the first embodiment
5 of a variable length antenna for transmitting or receiving at a
6 plurality of frequencies in accordance with the present
7 invention.

8 [0016] FIG. 3 is a schematic drawing of a second embodiment
9 of a variable length antenna for transmitting or receiving at a
10 plurality of frequencies in accordance with the present
11 invention.

12 [0017] FIG. 4 is a schematic drawing of a third embodiment of
13 a variable length antenna for transmitting or receiving at a
14 plurality of frequencies in accordance with the present
15 invention.

16 [0018] FIG. 5 is a schematic drawing of a fourth embodiment
17 of a variable length antenna for transmitting or receiving at a
18 plurality of frequencies in accordance with the present
19 invention.

20 [0019] FIG. 6 is a schematic drawing of a fifth embodiment of
21 a variable length antenna for transmitting or receiving at a
22 plurality of frequencies in accordance with the present
23 invention.

DESCRIPTION OF SOME EMBODIMENTS

2 [0020] The following description presents some embodiments
3 currently contemplated for practicing the present invention.
4 This description is not to be taken in a limiting sense, but is
5 presented solely for the purpose of some embodiments of
6 disclosing how the present invention may be made and used. The
7 scope of the invention should be determined with reference to
8 the claims.

9 [0021] FIG. 2 shows a first embodiment of a variable length
10 antenna for transmitting or receiving at a plurality of
11 frequencies in accordance with the present invention. In this
12 embodiment, variable length antenna 100 comprises a plurality of
13 antenna segments 110, 110a, 110b, 110c, 110d, 110e, ..., 110n, a
14 plurality of selectively actuatable switches 120a, 120b, 120c,
15 120d, 120e, ..., 120n, a switch controller 130, and a plurality
16 of light sources 140a, 140b, ..., 140m. As contemplated in this

17 embodiment, light sources 140a, 140b, ..., 140m, such as lasers,
18 pulsed lasers, light emitting diodes (LEDs), and diode lasers,
19 are operably coupled to switches 120a, 120b, 120c, 120d, 120e,
20 ..., 120n via optical fibers 150. However, other means, such as
21 optical waveguides, optical switches, light valves, and optical
22 MEMs devices, may also be used to couple light sources 140a,
23 140b, ..., 140m to switches 120a, 120b, 120c, 120d, 120e, ...,
24 120n. Switch controller 130 selects light sources 140a, 140b,
25 ..., 140m and switches them from a non-emissive to an emissive
26 state or from an emissive to a non-emissive state. When light
27 sources 140a, 140b, ..., 140m are in a non-emissive state,
28 antenna segments 110a, 110b, 110c, 110d, 110e, ..., 110n are
29 inactive and variable length antenna 100 has a length L with
30 output frequency F1. Switch controller 130 sequentially selects
31 and switches light sources 140a, 140b, ..., 140m from a non-
32 emissive state to an emissive state. As each of the light
33 sources 140a, 140b, ..., 140m are switched to an emissive state,
34 switches 120a, 120b, 120c, 120d, 120e, ..., 120n are actuated to
35 activate corresponding antenna segments 110a, 110b, 110c, 110d,
36 110e, ..., 110n and increase the effective length of variable
37 length antenna 100. Thus, when light source 140a is placed in
38 an emissive state, switches 120a and 120b are actuated, thereby
39 activating antenna segments 110a and 110b to form a dipole
40 antenna with length 2L and output frequency F2. Next, switch

41 controller 130 places light source 140b in an emissive state
42 which actuates switches 120c and 120d, thereby activating
43 antenna segments 110c and 110d to form a dipole antenna with
44 length $3L$ and output frequency F_3 . Finally, switch controller
45 130 places light source 140m in an emissive state which actuates
46 switches 120e and 120n, thereby activating antenna segments 110e
47 and 110n to form a dipole antenna with length nL and output
48 frequency F_m . When variable length antenna 100 has cycled
49 through the desired frequency range, switch controller 130
50 returns light sources 140a, 140b, ..., 140m to a non-emissive
51 state, and the sampling process repeats. When the required
52 switching and sampling times are met, variable length antenna
53 100 resembles a broadband antenna, with the advantage of using a
54 single highly efficient dipole antenna.

55 **[0022]** A second embodiment of a variable length antenna for
56 transmitting or receiving at a plurality of frequencies in
57 accordance with the present invention is shown in FIG. 3. In
58 this embodiment, variable length antenna 200 comprises a
59 plurality of antenna segments 210, 210a, 210b, 210c, 210d, 210e,
60 ..., 210n, a plurality of selectively actuatable switches 220a,
61 220b, 220c, 220d, 220e, ..., 220n, a switching device 230, and a
62 plurality of light sources 240a, 240b, ..., 240m. Optical
63 fibers 250 operably couple light sources 240a, 240b, ..., 240m
64 to actuatable switches 220a, 220b, 220c, 220d, 220e, ..., 220n.

65 As with the first embodiment, other means of operably coupling
66 light sources 240a, 240b, ..., 240m to actuable switches 220a,
67 220b, 220c, 220d, 220e, ..., 220n may be used, including optical
68 waveguides, optical switches, light valves, and optical MEMs
69 devices. In this embodiment, switching device 230
70 simultaneously switches light sources 240a, 240b, ..., 240m from
71 a non-emissive to an emissive state or from an emissive to a
72 non-emissive state. In addition, this embodiment of the present
73 invention includes the use of optical retarders 260a, 260b,
74 260c, 260d, 260e, ..., 260n coupled to optical fibers 250 to
75 change the effective lengths of optical fibers 250.
76 Alternatively, the physical lengths of optical fibers 250 may be
77 varied to introduce delay in the optical fibers 250 and achieve
78 the same effects of using optical retarders 260a, 260b, 260c,
79 260d, 260e, ..., 260n. When light sources 240a, 240b, ..., 240m
80 are in a non-emissive state, antenna segments 210a, 210b, 210c,
81 210d, 210e, ..., 210n are inactive and variable length antenna
82 200 has a length L with output frequency F1. Switching device
83 230 simultaneously switches light sources 240a, 240b, ..., 240m
84 from a non-emissive state to an emissive state. Optical
85 retarders 260a 260b, 260c, 260d, 260e, ..., 260n introduce
86 different amounts of delay into optical fibers 250 to
87 sequentially actuate switches 220a, 220b, 220c, 220d, 220e, ...,
88 220n. Switches 220a, 220b, 220c, 220d, 220e, ..., 220n are

selectively actuated to activate corresponding antenna segments 110, 110a, 110b, 110c, 110d, 110e, ..., 110n and increase the effective length of the antenna. Thus, when all light sources 240a, 240b, ..., 240m are placed in an emissive state, switches 220a and 220b are actuated first, thereby activating antenna segments 210a and 210b to form a dipole antenna with length $2L$ and output frequency F_2 . Next, switches 220c and 220d are actuated, thereby activating antenna segments 210c and 210d to form a dipole antenna with length $3L$ and output frequency F_3 . Finally, switches 220e and 220n are actuated, thereby activating antenna segments 210e and 210n to form a dipole antenna with length nL and output frequency F_m . When variable length antenna 200 has cycled through the desired frequency range, switching device 230 returns light sources 240a, 240b, ..., 240m to a non-emissive state, and the sampling process repeats. As with the first embodiment, when the required switching and sampling times are met in this embodiment, variable length antenna 200 resembles a broadband antenna, with the advantage of using a single highly efficient dipole antenna.

[0023] FIG. 4 shows a third embodiment of a variable length antenna for transmitting or receiving at a plurality of frequencies in accordance with the present invention. Variable length antenna 300 comprises a plurality of antenna segments 310, 310a, 310b, 310c, and 310d, a plurality of selectively

113 actuatable switches 320, a switching device 330 operably coupled
114 to a single multi-wavelength light source 340, and a plurality
115 of diffraction gratings 370. In this embodiment of the present
116 invention, switching device 330 switches the single light source
117 340 from a non-emissive to an emissive state or from an emissive
118 to a non-emissive state. When light source 340 is placed in an
119 emissive state, the light passes through diffraction gratings
120 370 and produces a plurality of new light sources after
121 diffraction. As with the second embodiment, this embodiment
122 employs the use of optical retarders 360 to introduce delay and
123 change the effective lengths of optical fibers 350. The
124 physical lengths of optical fibers 350 may also be varied to
125 achieve the same delay effects of optical retarders 360. Thus,
126 switches 320 are sequentially actuated to activate corresponding
127 antenna segments 310a, 310b, 310c, and 310d and increase the
128 effective length of variable length antenna 300.

129 **[0024]** FIG. 5 shows another embodiment of a variable length
130 antenna for transmitting or receiving at a plurality of
131 frequencies in accordance with the present invention. Variable
132 length antenna 400 is a pressure-driven liquid antenna
133 comprising two separate liquid metal columns 410, each held in
134 its own dielectric tube 412. The pressure in the dielectric
135 tubes 412 is controlled by a pressure regulator system
136 comprising of pumps 420 operably coupled to one end of the

dielectric tubes 412 via hoses 422 and reservoirs 424 for holding excess conductive fluid 410. Additional pumps 426 may operably couple the reservoirs 424 to the dielectric tubes 412. Increasing the pressure in the dielectric tubes 412 in conjunction with pumping conductive fluid 410 into the reservoirs 424 shortens the length of the antenna 400. Reducing the pressure in the dielectric tubes 412 in conjunction with pumping conductive fluid 410 from the reservoir 424 lengthens the antenna. This embodiment of the present invention may be readily formed using microfabrication techniques such as those used in microfluidic and MEMS processing. In such cases, channels may be formed in dielectric material that can provide the form or structure for the antenna.

[0025] Another embodiment of a variable length antenna for transmitting or receiving at a plurality of frequencies in accordance with the present invention is shown in FIG. 6. In this embodiment, variable length antenna 500 comprises a plurality of antenna segments 510, 510a, 510b, 510c, ..., 510n, and a source of at least one electromagnetic beam 520 for decoupling antenna segments 510, 510a, 510b, 510c, ..., 510n. Illuminating a section of the variable length antenna 500 with an electromagnetic beam decouples the segment of the antenna beyond the point of illumination from the rest of the antenna and, thus, varies the effective length of the antenna. To

161 decouple an antenna segment, the intensity of the
162 electromagnetic beam 520 must be sufficient to overwhelm any rf
163 signal on the antenna at the point of beam illumination. Two
164 possible sources for the electromagnetic beams are the hydrogen
165 cyanide (HCN) laser, which has a frequency of 890 GHz, and the
166 hydrogen atom maser, which has a frequency of 1.42 GHz.

167 [0026] An important aspect of the variable length antenna for
168 transmitting or receiving at a plurality of frequencies is the
169 flexibility in its range of frequencies. The number of actuatable
170 switches and antenna segments may be increased or decreased
171 depending on the desired frequency range. Moreover, the
172 operation of the variable length antenna is not limited to
173 sequentially transmitting or receiving frequencies within the
174 frequency range. The present invention may be operated to
175 transmit or receive frequencies in any desired sequence within
176 its frequency range. Finally, this concept may be applied to
177 other radiating apertures including, but not limited to, slots,
178 spirals, and the like.

179 [0027] Obviously, many modifications and variations of the
180 invention are possible in light of the above teachings. It is
181 therefore to be understood that within the scope of the appended
182 claims the invention may be practiced otherwise than as has been
183 specifically described.